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The Introduction of Exchange Traded Weather Derivatives in India: A New Era of Risk Management

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Abstract : This Weather fluctuations are common but unpredictable, with significant consequences for industries. Weather derivatives, financial contracts that hedge weather-related risks, have been available since 1997 in the US and other countries. While weather derivatives have been traded OTC in India for a long time, their adoption has been limited. However, on March 1, 2024, India's Ministry of Finance expanded the list of items permitted under the Securities Contract Regulation Act (SCRA) of 1956 commodity trading rules to allow weather derivatives to be traded on exchanges. This expansion will benefit the agricultural industry, which contributes 30% of India's GDP and is directly impacted by weather. Other industries, such as tourism, energy, construction, and mining, can also use weather derivatives to hedge against weather-related risks. Weather derivatives can be based on various weather underlyings, such as temperature, rainfall, windiness, and radiation, and can take the form of futures, forwards, options, or swaps. This study emphasizes to determine importance and scope of weather derivatives in India, review of pre-existing methodologies of pricing weather derivatives, understand Payoffs of such contracts, suggesting suitable baseline for calculation of HDD and CDD.

***Index Terms* - Weather Derivatives, Commodity Derivatives, SCRA, India, Exchange Trading, Weather Risk Management**

I. INTRODUCTION

A derivative is a financial contract that derives its value from an underlying asset such as a currency, stock, market index, interest-bearing security, or physical commodity. Derivatives can be classified as forwards, futures, options, or swaps depending on how the payoff is structured. The primary objectives of using a derivative contract are hedging, speculating, and arbitrage, with hedging being the most significant and the original objective. The primary purpose of derivative contracts is to mitigate and transfer risk to a party willing to take an opposite exposure and to hedge against losses arising from weather-related risks, such as unexpected temperature increases or decreases, excessive or low rainfall, and other weather-related events. Many industries, including leisure and tourism, energy production and consumption, construction, agriculture, and mining, are directly related to and exposed to weather-related risks, creating an opportunity for them to be hedged using weather derivatives. In India, weather derivatives have been traded over-the-counter (OTC) for a long time, but their volume has been relatively low. However, in a recent notification on March 1, 2024, India's Ministry of Finance expanded the list of items permitted under the Securities Contract Regulation Act (SCRA) of 1956 commodity trading rules. The list of allowable items was increased to 114 (from 91) by adding 13 more items including weather derivatives. The goal of this expansion is to facilitate better price discovery, encourage liquidity, and make access to such derivatives contracts easier.

The agriculture industry is one of the industries that is directly impacted by weather and contributes around 30% of the Indian GDP, while the tourism sector contributes 6.3% to Indian GDP,making introduction of weather related derivatives on exchanges essential.

Commodity producers and consumers can now protect themselves from price fluctuations by using online trading in commodity futures, which provides traders with a new platform for price stabilization. In addition, weather derivatives have proven to be crucial tools for hedging against the risks of adverse weather conditions. As a result, the Indian derivative market offers a hedging model that utilizes the HDD and CDD Index approaches.

The profitability and revenue of numerous industries, including agriculture, energy, entertainment, construction, and travel, are largely determined by unpredictable temperature, rainfall, and storm patterns. Unanticipated weather conditions often result in price adjustments that fail to fully compensate for lost revenue, making weather derivatives securities, which enable businesses to protect themselves against adverse weather conditions, a crucial investment.

Companies with operations that are influenced by the weather, such as hydroelectric power plants or event managers, may utilize weather derivatives as part of their risk management strategies. Similarly, farmers may use weather derivatives to mitigate the risks associated with poor harvests caused by excessive or insufficient rainfall, extreme temperature fluctuations, or damaging winds.

1.1. The Main Features of the Weather Derivative

The amount of money paid or received for each unitary movement of a chosen meteorological variable is referred to as tick size. This value indicates the payment or collection to be made for each unitary temperature movement, and the high and low limits establish a "corridor" of payments, setting a maximum outlay and collection. A strike is the value above which the payment or collection is made. Weather derivatives can be established on various weather underlyings, such as temperature, rainfall, windiness, and radiation, depending on the specific quantity that affects the margins. The most commonly used underlyings are as follows.

* Temperature [°C]

a) HDD–Heating Degree Day: This is calculated as the difference between the average daily temperature and a threshold value, typically 18 °C. This index is used to manage the temperature exposure during winter.

b) CDD - Cooling Degree Day: This is equivalent to HDD for the summer period.

c) CAT - Cumulative Average Temperature: It is summation of the temperatures recorded over a specified period.

* Rain [mm]
* Wind [m/s - Km/h - knots]
* Radiation [W/m2]

Weather derivatives are financial instruments employed by businesses or individuals to minimize the risk of adverse or unexpected weather conditions. These financial derivatives differ from others in that underlying assets, such as rain, temperature, snow, wind, or a combination of two or more, have no inherent value in determining the price of the weather derivative. The weather derivatives market, as identified by the Weather Risk Management Association (WRMA), consists of two primary aspects: managing the financial consequences of severe weather for those with direct exposure to it and engaging in weather-related commercial transactions, both independently and in conjunction with a wide range of commodities. Similar to other financial derivative contracts, weather derivative contracts can take the form of Futures, Forwards, Options, and Swaps.

The underlying in such contracts may specifically be:

1. Temperature: The most common types of temperature-based indices used heating degree days (HDD) and cooling degree days (CDD), where the base temperature is regarded as 18 °C or 65°F, worldwide. Some may also be utilizing normal departure index (NORDIX) which denotes how "normal" or "strange" a given year or occurrence is whilst collating it to the long-term average for the region or area under examination. Apart from these, maximum, minimum, or average daily temperatures are used.

2. Precipitation: An index based on precipitation is employed for areas where rain or snow are prominent to the weather derivatives market participants who wish to hedge from weather-related risks. Indices of such derivatives contracts are based on rainfall and snowfall levels.

3. Wind: Several weather derivatives contracts are also based on wind speed along a specific direction, wind farm output and variance, that is, variability is the wind. The risks that industries confront differ, as do the sorts of indices that they use. However, it is observed that maximum of the weather derivatives contracts is based on temperature-based weather indices. The most used underlying is the Degree Days, specifically, Heating Degree Days (HDD) and Cooling Degree Days (CDD). The HDD index is employed during the winter months and gauges cold waves. A higher index indicates a colder day, indicating higher demands for heating as a corollary, and vice versa. Therefore, it can be computed as HDD= (0, base temperature- actual temperature), that is, HDD= (0, 65° F- T). This means that the payoff would be zero if the actual day temperature is more than the base temperature; in case the actual day temperature is lower than the base temperature, the payoff would be the difference between the two. The CDD index, per contra, is used during the summer months and measures the heat. A higher index denotes a higher temperature, indicating a higher demand for cooling and vice versa. It can be computed as CDD= (0, actual temperature- base temperature), that is, CDD= (0, T- 65°F), which means that the payoff would be zero if the actual day temperature is less than the base temperature, and it would be the difference between the two if the actual day temperature is more than the base temperature. All weather derivative contracts delineate the following essentials:

1. The location of the contract,
2. The underlying
3. The strike price, that is, the predetermined price at which the derivative contract will be bought and sold at the time of execution of the contract
4. The expiration date, that is, the last day the derivative contract is valid
5. Notional value, indicating the total amount of the underlying
6.The time period for measurement of HDD and CDD

II. Objectives of Study

The objectives of this study were as follows:

1) To determine importance and scope of weather derivatives in India
2) Review of pre-existing methodologies of pricing weather derivatives
3) Understand Payoffs of such contracts
4) Suggesting suitable baseline for calculation of HDD and CDD

III. IMPORTANCE OF WEATHER DERIVATIVES IN INDIA

Over the past few decades, some countries have focused on implementing and strengthening crop insurance programs as part of their agricultural policies. However, traditional agricultural insurance schemes are often plagued by problems, such as asymmetric information and systemic risks, which require substantial government support to operate effectively. By implementing these programs, policymakers aim to create more market-oriented policy instruments that reduce producers' reliance on disaster aid and promote more efficient and equitable use of resources. As a result, a variety of innovative and sophisticated crop insurance programs have been developed and tested, with the most advanced experiences found in countries such as Canada and the United States, which offer a range of policies, including multi-peril revenue and income products and area-based multi-peril revenue and income schemes. In addition, recent innovations in energy markets suggest that derivatives based on weather elements could be used to address agricultural risk factors, which could result in cost savings and improved market transparency from an agricultural policy perspective.

As an agriculturally based economy, India can readily adopt weather derivatives. Agriculture accounts for approximately 30% of the nation's GDP, and more than half of its agricultural sector relies on rainwater irrigation. Given this information, it is clear that rainfall and temperature are closely related to the market. Thus, the introduction of exchange-traded weather derivatives is a significant move by SEBI.

Apart from the agricultural sector, the Indian tourism industry ranks as one of the fastest-growing economic sectors in the country, contributing 6.3% of India's total GDP. Like the agricultural and energy sectors, the leisure and tourism industries are directly impacted by weather conditions such as precipitation, temperature, and frost. Therefore, the introduction of exchange-traded weather derivatives is crucial to hedge against weather-related risks in this sector.

IV. PRE-EXISTING METHODOLOGIES OF PAY-OFF CALCULATION AND PRICING OF OPTIONS

The first exchange-traded weather derivatives were launched by the CME in 1999, and since then, many exchanges across the globe have introduced their own weather derivatives, which are somewhat mirror images of the CME model with few alterations. There is a huge possibility that India will adhere to this framework.
The following is the calculation of the payoffs:
The payoff is calculated based on the historical function data of the HDD and CDD. To calculate the HDD and CDD, we need three data points:
1) High- Maximum Temperature of the day: T_n^{Max}
2) Minimum- Minimum Temperature of the day: T_n^{Min}
3) Average- average temperature of the day: T_n

$$T_n = \frac{T_n^{Max} + T_n^{Min}}{2}$$

On each day (period) $n \in N$

- The Heating Degree Days is defined as $HDD = \{0, (T_{ref} - T_n^{Max})\}$
- The Cooling Degree Days is defined as$CDD = \{0, (T_n^{Min} - T_{ref})\}$
- The Heating Degree Days is defined as $HDD = \{0, (65 - T_n^{Max})\}$
- The Cooling Degree Days is defined as$CDD = \{0, (T_n^{Min} - 65)\}$

(65° F is the baseline temperature assumed)
Here the payoff of option buyer will be $=f(DD)$

The payoff function f is computed on cumulative index over a period *P:*

- The Heating Degree Season is defined as $DD = H_n = HDD^N = \sum_N^n \quad HDD_n$
- The Cooling Degree Season is defined as $DD = H_n = CDD^N = \sum_N^n \quad CDD_n$

Degree-days are based on the assumption that when the outside temperature is 65°F, heating or cooling is not required to be comfortable. Degree days are a metric that is calculated by subtracting the average daily temperature (obtained by adding the high and low temperatures and dividing the sum by two) from 65°F. If the average temperature is greater than 65°F, the resulting value is referred to as a cooling degree day, whereas if the average temperature is below 65°F, the resulting value is referred to as a heating degree day.

This baseline temperature for calculating HDD and CDD is only used by CME in the USA based on the historical trends of temperature in the USA. Degree Days in UK are calculated using 60°F.
The calculation of the baseline temperature of each country must be unique to the historical trends of the average weather of that country, rather than the mirroring model of any other country.

A research project carried out in Jaipur, India, among healthy young male participants revealed that the neutral thermal comfort temperature was assessed to be 30.15 °C (86°F), with a range of 25.9–33.8 °C (79–93°F). Thus, baseline temperature for calculation of payoff must be **arithmetic mean of 79 and 93°F i.e. 86°F.**

4.1. Pricing Methodologies of Weather Derivatives

Another issue is the pricing of weather derivatives. One cannot buy or sell the underlying material, such as sunshine or rain. The position must be hedged with offsetting positions, and one cannot create a risk-free portfolio by combining the derivatives with its underlying (as done for other derivatives). Weather contracts are based on forecasting; therefore, information on past weather behaviors and an understanding of the dynamics of the environment are essential. First, it is important to collect and compile the relevant temperature data from a trusted meteorological station. After that, we need to model seasonality, for which we need to de-trend and remove seasonality by classical decomposition using moving averages and then de-trend and model the seasonal component as a Fourier series.

For modelling temperature, we may look two approaches, Time Series ARMA model and mean reverting Ornstein-Uhlenbeck process. Thus, we can use statistical analysis of historical temperature and models to price options.

The actuarial approach to pricing weather derivatives, such as historical burn analysis, involves using historical weather data to estimate the likelihood of future weather events and their associated financial impacts. This method typically assumes that past weather patterns are indicative of future trends and uses statistical techniques to calculate the expected payouts of weather derivatives based on historical frequencies and severities of weather events (Richards et al., 2004). However, there are limitations and considerations to this approach. For instance, the historical burn analysis may not account for changing weather patterns due to climate change or may not incorporate forward-looking information such as meteorological forecasts or the implied market price of risk (MPR), which can be critical for accurate pricing (Bernard et al., 2015; HHrdle et al., 2012). Additionally, the actuarial approach may not fully capture the market dynamics and the statistics of changes in probabilistic meteorological forecasts, which can be essential for managing the short-term risk distribution of weather derivative portfolios (Jewson, 2002). In summary, while the actuarial approach, including historical burn analysis, provides a foundation for pricing weather derivatives, it is important to recognize its limitations. Incorporating additional information such as meteorological forecasts, market dynamics, and the MPR can enhance the accuracy of pricing models. The actuarial method is one of several approaches, and its appropriateness may vary depending on the specific characteristics of the weather derivative being priced and the market conditions (Richards et al., 2004; Wang et al., 2010).

Weather derivatives can also be priced using Monte Carlo simulations that incorporate time series data and the Ornstein-Uhlenbeck (OU) model The OU model is a mean-reverting stochastic process often used to model temperature dynamics for weather derivative pricing (Wang et al., 2015). Time series data, which captures historical temperature patterns, is essential for calibrating the parameters of the OU model, such as the mean reversion level, speed, and volatility (Tong & Liu, 2020; Wang et al., 2015). Interestingly, while the OU model is a common choice for its mean-reverting property, some studies have modified it to better capture the seasonal variations and stochastic volatility observed in temperature data. For instance, a time-changed OU process with seasonally varying parameters has been proposed to improve the fit to the temperature time series (Tong & Liu, 2020). Additionally, the Gamma OU model has been discussed for its ability to capture financial time series features and for pricing options, which could be adapted for weather derivatives (Mi, 2011; Mi, 2016). In summary, to price weather derivatives using Monte Carlo simulations with time-series data and the OU model, one must first calibrate the OU model parameters using historical temperature data. The calibrated model can then be used to simulate future temperature paths, and the Monte Carlo method can be applied to estimate the price of the derivative. The choice of the OU model variant and the calibration method can significantly affect the pricing accuracy, and modifications to the basic OU model may be necessary to account for seasonal patterns and stochastic volatility (Mi, 2011; Mi, 2016; Tong & Liu, 2020; Wang et al., 2015).

V. Findings

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While the models and methodologies of pricing options can be replicated from pre-existing models developed by CME, variations and alterations are essential to ensure robustness and accuracy of model and for that **65°F cannot be used as baseline temperature for calculating HDD and CDD, rather 86°F must be used, being ideal comfortable room temperature in India.**

IV. Conclusion

Countries are implementing crop insurance programs to reduce reliance on disaster aid and promote efficient resource use. Advanced crop insurance programs, such as multi-peril revenue and income products in Canada and the United States, have been developed. In the energy markets, weather derivatives could address agricultural risk factors, leading to cost savings and improved market transparency. India, with 30% of its GDP based on agriculture, can easily adopt these derivatives. The Indian tourism industry, a fast-growing sector, is also impacted by weather conditions, making the introduction of exchange-traded weather derivatives crucial for hedging against risks.

The main purpose of weather derivatives is to hedge risk associated weather, a major share of Indian economy is directly dependent on weather, thus making it essential to introduce exchange traded derivatives for more liquidity, standardization of contracts, better price discovery and achieving greater trading volume.
The payoff in such derivatives is a function on HDD and CDD (in case temperature is the underlying). While calculating HDD or CDD a baseline temperature is assumed, that must be 86°F based on India's ideal temperature.

The price of options can be calculated using statistical analysis of historical temperature data using Monte Carlo simulations incorporating time series data and the Ornstein-Uhlenbeck (OU) model. The OU model is a mean-reverting stochastic process used to model temperature dynamics. Historical temperature data is crucial for calibrating the parameters of the OU model, such as mean reversion level, speed, and volatility. Some studies have modified the OU model to better capture seasonal variations and stochastic volatility. The choice of OU model variant and calibration method significantly affects pricing accuracy, and modifications may be necessary to account for seasonal patterns and volatility.

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